Comparing the cost of emission reductions in first and second-best economies

by

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Abstract
In a sequence of illuminating papers Goulder, Parry, Burtraw and Williams decompose the effects of using environmental instruments like taxes and quotas within a second-best setting, i.e., in the presence of pre-existing taxes. We find this part of their analyses most revealing.

They also perform numerical analyses from which they conclude that pre-existing taxes raise the costs of environmental policies relative to their costs in a first-best world. The observation is valid as far as the *marginal* cost per percentage emission reduction is concerned, but not so for *total* welfare costs of obtaining an emission target. In fact, employing their model we demonstrate by computing the excess burden of taxation, that the second-best welfare index falls at a slower rate than the first-best welfare index, such that the welfare costs of reducing emissions in second best are lower.

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1. Introduction

Traditionally, papers on environmental economics used to consider the instruments for environmental protection in isolation from other policy instruments, notably the actual tax system[1]. In the late 80's and beginning of the 90's, however, the idea evolved that the revenues from environmentally motivated taxes could be used to lower the rates on existing, distortionary taxes giving rise to the notion of a ”double dividend” from introducing environmental taxes. (Cf. Pearce (1991).) The idea was that the environmental tax would both increase environmental quality (the first dividend) and allow for further gains (the second dividend) when existing, distortive tax rates were reduced.

When this issue was analysed further, however, “some quite astonishing and very troubling findings emerged.” [Oates (1995).] These may be summarised as follows: The new taxes (or auctioned quotas) on environmentally harmful goods or factors will interact with the existing taxes and compound the degree of distortions already in place. This ”tax interaction” effect implies that the tax system becomes more distortive. If, on the other hand, the revenues from the green taxes are used to reduce the rates of existing distortionary taxes, one obtains a ”revenue recycling” effect, which works to reduce the distortions. The net welfare effect of the tax-interaction and the revenue-recycling effects is ambiguous; although one might say there is a bias towards a negative net effect.[2]

In three recent papers, Goulder et al (1997), Parry et al (1999) and Goulder et al (1999) (henceforth GP) compare the costs of obtaining emission reductions in first- and second-best economies by means of numerical analyses. Of course, in an economy without distortions (apart from too high emissions), there are no pre-existing taxes to interact with as one introduces environmental taxes. Also, there are no distortive tax rates to cut back on when using the revenues of the environmental taxes; instead, lump-sum taxes are reduced. Hence, there is neither a tax-interaction nor a revenue-recycling effect.[3] Comparing the welfare

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[1] According to Browning (1997), the tendency to consider a distortion (e.g. an externality or monopolistic pricing) in isolation, or against a background of a competitive economy, is fairly general within welfare economics.

[2] Analysts claim that ”environmental taxes typically exacerbate, rather than alleviate, pre-existing tax distortions” (Bovenberg and de Moiij, 1994), implying that ”[in] general the negative welfare impact of the tax-interaction effect dominates the positive influence of the revenue-recycling effect ..” (Goulder et al, 1997; see also Goulder et al, 1999, and Parry et al, 1999). Different assumptions in their models are known to cause opposite results. (Parry et al. (1999), end of section 2.2.) Hence, the sign of the net effect is an empirical question, and the result may differ from one economy to the other. Studies of the Norwegian economy, for example, indicate the possibility of a positive net welfare effect (Håkonsen and Mathiesen (1997), Bye (1997)) while Goulder (1995) compute a clearly negative welfare effect for the US economy.

[3] Revenue recycling is here used in the narrow sense that has become usual in the recent literature – the welfare gain associated with reduced rates on existing tax rates. Revenues from the environmental tax are recycled also in a first best economy – through lump sum transfers (reduced lump sum taxes) in stead of reduced rates.

effects from environmental taxation in first- and second-best economies therefore requires careful analysis.

GP find that ”pre-exisiting taxes raise the costs of environmental policies relative to their costs in a first-best world”.[4] Throughout their papers one can easily get the impression that this statement refers to the total welfare cost of environmental regulation. What they show, however, is that the *marginal* cost per percentage reduction is higher in second best than in first best. Because the undistorted first-best economy operates at a higher activity level, both its welfare index and unregulated emissions are higher than in the corresponding second best equilibrium. Thus, one cannot easily infer total welfare costs from marginal costs, and we think their presentation is misleading and may provide fundamentally wrong signals to both analysts and policy makers. The analyst may think that by ignoring the present tax system of the economy, his model of the (first-best) economy will *under*estimate the true welfare cost of regulation, while according to our interpretation he *over*estimates the cost. The political decision maker being concerned about welfare costs, is more likely to think that regulation in the actual economy is too costly and hence abstain from action.

We suggest using the excess burden to compare welfare costs from regulation. With their numerical model (Parry et al (1999)), we re-establish the main intuition from the initial papers on double dividends (e.g. Pearce (1991)): If the revenue from environmental taxes is used to cut back on existing distortionary taxation, *emission reductions cost less in second best than in first best*. To see this point, consider a first-best tax system where revenue is raised by means of a lump sum tax and a second-best tax system where revenue is raised by a tax rate on labour income. Without emission taxes, the first- and second-best tax systems have no common tax instruments. When regulating emissions by an emission tax, however, some revenues in both systems originate from the same tax base: the emitting activities. This has the effect of diminishing the difference between the systems in terms of inefficiency; there is convergence. Assume the rather hypothetical case that environmental taxes could generate sufficient revenue to fund the entire public budget so that there was no need for distortionary taxes at all. First- and second-best regulated[5] solutions would then coincide and be equally efficient. Because the first-best tax system is the more efficient before regulation, and the two

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[4] This is from Goulder et al. (1999). Similar statements are made in the two other papers.

[5] Admittedly, it is a contradiction of concepts to talk of a regulated first best equilibrium. If it is regulated, it is not first best; and by definition, in a first best equilibrium there are no distortions to the markets from taxes, externalities, or any other violations of the competitive economy, hence no need for regulation. So by first best regulated equilibrium, we simply mean a solution where, except from environmental quality, all other conditions for the competitive equilibrium is met.

economies are equally efficient when regulated, the welfare cost of regulating the first-best economy is the largest.

In the next three sections we draw up a simple theoretical basis for our computations, re-establish the numerical model used by Parry et al (1999), and then interpret our results obtained from their model. Section 5 concludes.

2. Theoretical foundations

The numerical model used by Parry et al (1999) represents an economy for which the Diamond-Mirrlees (1971) production efficiency theorem holds. There is constant returns to scale and zero pure profits, and the set of second best optimal taxes involves no taxes which distort the input choices of the producers, i.e., there are no taxes on intermediate inputs. Second best optimal taxes must therefore be levied on the household's supply of labour and demand for final consumption goods. Let t_L, t_I, and t_N denote tax rates on labour income and consumption of respectively the energy-intensive and the non-energy-intensive consumption goods. Since there is no pure profit, one of the tax rates may without loss of generality be set to zero, Munk (1978). Choosing $t_I = 0$, the operational tax rates are t_L and t_N. The assumed preference structure, where leisure is weakly separable from the consumption aggregate, implies that the two consumption goods are equally strong substitutes to leisure, whereby a second-best optimal tax rate on non-energy-intensive consumption is zero. The second-best tax solution, before we introduce an emission target, is therefore very simple: Choose t_L sufficiently high to meet the exogenous tax revenue requirement. A first-best tax solution is equally simple: The lump sum tax, denoted a, finances the exogenous revenue requirement and other tax rates are zero. Disregarding environmental concerns, the single restriction on the government's policy instruments is that the tax revenue requirement must be met.

When introducing a restriction on carbon emissions, $e \leq e^*$, the tax rates must fulfil the following two restrictions:

$$\begin{aligned} REV \geq t_e e + t_L L + a = G, \\ e \leq e^*. \end{aligned} \tag{1}$$

In (1), G represents a nominal income transfer, and t_e is the tax rate on carbon emissions. In the computations, the transfer is kept constant in real terms, i.e., $G_R = G/p_U$ is constant, where p_U is the ideal price index representing the true cost of living (the unit expenditure function).

The total excess burden caused by distortionary taxation represents a measure of how much better off the representative consumer would have been if the same amount of tax revenue were collected by means of non-distortionary finance. Pauwels (1986) shows that the equivalent variation when going from the first best to a distortionary equilibrium (raising the same amount of revenue) represents a valid measure of the total excess burden.

3. A numerical model of the US economy

Based on a numerical model of the US economy, Parry et al (1999) analyse the costs associated with reductions of CO_2 emissions. We establish the model from the information they provide in their table 1 and appendix. In order for our paper to be self-contained, the model, our numerical implementation and benchmark data are stated in appendices A and B.

The following figure is a reconstruction of their Figure 1. The marginal costs are computed as the equivalent variation per unit emission reduction.[6]

> “[The grandfathered] quota policy shifts up the marginal cost curve, giving it a positive intercept. This upward shift reflects the tax-incidence effect. Under the carbon tax, the marginal cost curve pivots upward but retains the zero intercept that applies to the first-best case. [..] The zero intercept reflects the fact that the revenue-recycling effect exactly offsets the tax-interaction effect at the first increment of abatement.” [Parry et al (1999).]

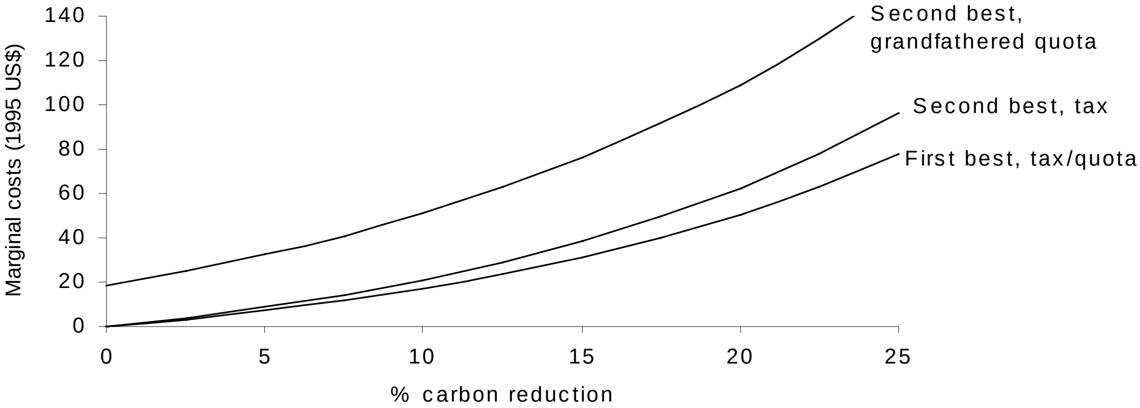

Figure 1. Marginal cost schedules in first- and second best

The figure shows marginal costs of emission reductions in first and second best. Clearly the second-best curves portray higher costs for equal percentage reductions. Can we from these plots of marginal costs infer that total welfare costs of regulation are larger in second best

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[6] At each five per cent reduction level, carbon emissions are reduced by 0.1 million tons, the resulting equivalent variation in millions of dollars is computed, and the marginal cost figure measured in dollars per ton is derived.

than in first best? We think not, because the first and second-best economies differ in two respects, viz. welfare and emissions, neither of which is adequately represented in Figure 1.

All three papers (Goulder et al (1997), Parry et al (1999) and Goulder et al (1999)) include statements of the following nature: “pre-existing taxes raise the *costs* of environmental policies relative to their costs in a first-best world.” If one restricts the notion of costs to that of *marginal* costs, and compare percentage reductions from different absolute levels, they are right. We would think, however, that the typical reader gets the idea that these statements apply to *total* costs, but with such interpretation these statements are invalid.

4. Emission reductions and efficiency differences

A labour income tax distorts the labour-leisure choice, reduces the labour supply and makes the second-best economy operate below its maximum, as implied by the labour endowment and an undistorted labour-leisure choice. With our version of their model, we compute that the first-best economy would operate at 15.2 % higher activity level, and that the equivalent variation of going from first to second best (without any concern for the environmental quality) is 116.5 billion dollars. This amounts to approximately 2.5% of the full endowment income in the second-best benchmark equilibrium and represents the excess burden caused by the benchmark income tax rate of 40%.

By reducing the labour supply and the activity level of the economy, the labour tax also reduces emissions, such that total emissions in the first and second-best equilibria are 1639 respectively 1424 million tons.[7] Compared to the first best, the second-best economy provides less consumption (a welfare loss), but also less emission (a welfare gain). When evaluating the efficiency of the second-best economy based on that of the first best, one should observe both of these differences. In particular, remaining emissions should be noticed as one would think they, and not reduced emissions, are drivers of damage costs. (Parry et al (1999) convey the same view by writing the utility function as $u(C_F, C_N, l) - \phi(F)$, where F is emissions and $\phi(F)$ is disutility from emissions.) Hence, we think the excess burden from regulation (and pre-existing taxation) of the two economies should be compared against the background of remaining emissions.

Consider the following exercise: Starting at 1639 million tons, reduce the cap e^* on total emissions and compute the equivalent variation for both economies. See Figure 2. The

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[7] For each activity, their model employs a fixed coefficient of carbon content. Thus, higher activity levels come with higher total emissions. We compute that total emissions amount to 1639 million tons in the first-best case.

constraint $e \leq e^*$ binds immediately in first best, while it remains slack in second best until e^* reaches the benchmark level of 1424. Although there are no distortions in first best at e* = 1639, by the time the cap reaches 1424, the emission tax has reduced the utility from leisure and consumption goods in the first-best economy, while the second-best equilibrium is unaffected. By reducing the cap further, both equilibria are affected.

At e^* = 900, the first-best welfare cost of the emission tax is 80.4 billion dollars, indicated by the lowermost arrow. The welfare cost of obtaining the *same emission target* in the second-best equilibrium, however, is the differential cost of 43.8 billion dollars (= 160.3 – 116.5) as indicated by the uppermost arrow, and not the entire 160.3. Thus, the welfare cost of regulating the second-best economy amounts to only a little more than half the cost of regulating in the first-best setting. What seems to be lost by GP's way of considering the relative efficiencies of first and second best, is the revenue-recycling effect. In second best, where revenues from the carbon tax replace revenues from the labour tax, the inefficiencies caused by the carbon tax cut into and partially replace the inefficiencies caused by the labour tax. The first best does not offer this possibility of alleviation. We observe, however, that the tax-interaction effect dominates the revenue-recycling effect[8], whereby the second-best curve increases. It would otherwise slope downwards, as e.g. shown by Håkonsen and Mathiesen (1997).

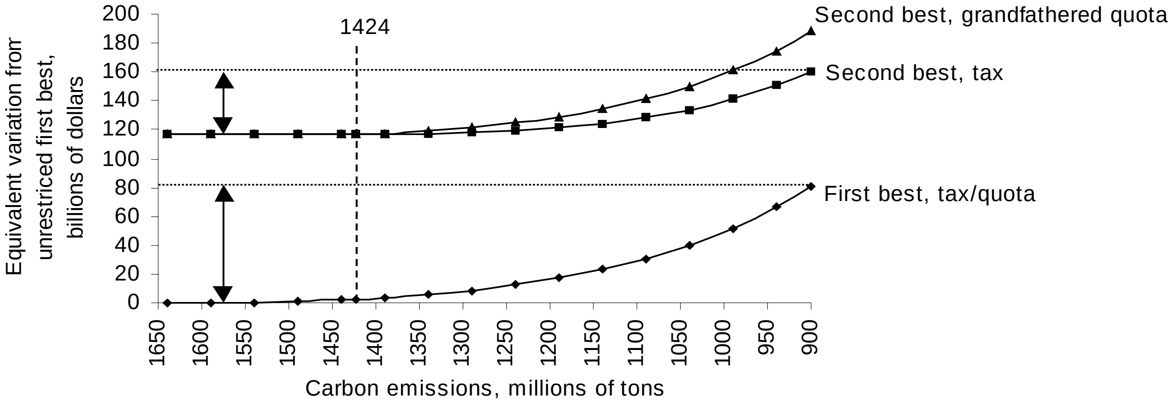

Figure 2. Equivalent variation from unrestricted first-best equilibrium

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[8] "In general, the negative welfare impact of the tax-interaction effect dominates the positive influence of the revenue-recycling effect and **implies** that, overall, environmental regulations are more costly in a second-best setting with preexisting distortionary taxes than in a first-best situation where no other taxes are present." [Goulder et. al (1997), footnote 2. Emphasis added.] As our results demonstrate, the implication is not true, unless one interprets 'costs' as marginal costs per percent reduction. It seems they forget that it is costly to regulate in first best as well. A complete statement of the cost-difference between second and first best is: tax-interaction effect – revenue-recycling effect – first-best cost = vertical distance between the second best/tax and first best curves in Figure 2.

The excess burden (*EB*) associated with a second (or third) best equilibrium involves a comparison with a first-best solution yielding the same tax revenue. (See Pauwels (1986).) At the unrestricted first-best equilibrium, e = 1639, *EB* can be read from Figure 2 as the vertical distance between the first- and second-best tax-curves, i.e., 116.5 billion dollars. With an emission target e^*, the excess burden becomes contingent upon that target, i.e., $EB(e^*)$. We see that the two tax-curves converge.[9] At e^* = 900, *EB* is reduced to 79.8 billion dollars. Observe that this is when the revenue-recycling effect is exploited. When the carbon revenue is given away through grandfathered quotas, however, the excess burden is 107.7. Thus, reducing emissions by means of grandfathered quotas inflicts an extra EB compared to a regulation with emission tax or auctioned quotas. At e^* = 900, this additional EB amounts to 27.9 billion dollars, or almost 65% over and above the welfare cost of the carbon tax.

Perhaps our argument of the relative costs becomes more transparent if we modify one parameter in the numerical model, namely the level of taxation. Assume that the labour tax rate is 20 and not 40%, and that the governmental revenue requirement is reduced accordingly. Let us redo the experiment of reducing the emission cap from its maximum, which still is 1639. Because of the reduced tax rate, the distortion from taxation in second best is smaller, and the excess burden of the unregulated second-best economy is reduced from 116.5 to 21.4 billion dollars. The overall activity level in second best is larger and results in total emissions of 1551 million tons.

Figure 3 displays EB as a function of the emission target. At e* = 658 million tons, the emission tax is sufficient to generate the governmental revenue requirement. Thus, the reform of replacing the labour tax with an environmental tax, coincides with the first-best solution to environmental regulation.[10] The two model economies are then equally efficient and provide the same welfare. Because the welfare costs are zero when the first-best economy is unregulated, and the welfare costs of the two are equal when both are regulated, we conclude that the welfare costs from regulation in the first-best economy is the larger.

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[9] According to the model, the two curves meet when emissions are reduced to 389 tons.

[10] This is essentially Sandmo's observation. Sandmo (1995).

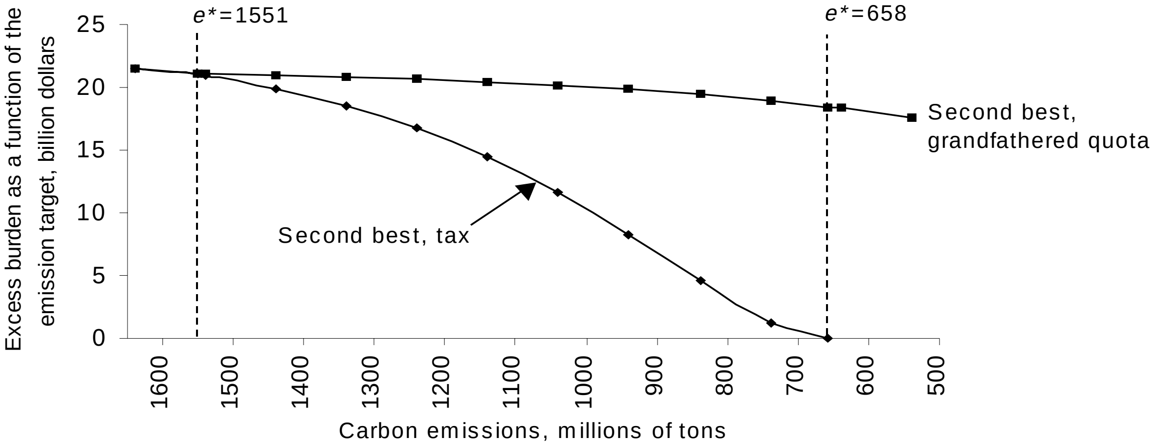

Figure 3. Excess burden as a function of the emission target *e.**

We observe that grandfathered quotas do not allow for efficiency-convergence, since this way of regulating emissions does not exploit the benefits of revenue recycling. In stead of being reduced in the example of Figure 3, the labour income tax rate increases from 20% to 22% as the carbon emissions are reduced from 1551 to 658 million tons.[11]

5. Concluding comments

We have used Parry et al's (1999) CGE model of the US economy to compute the welfare costs of regulating carbon emissions in first- and second-best settings. We find that it is less costly to regulate in second best than in first best. Parry et al's claim to the opposite, stems from comparing marginal costs of percentage emission reductions. We think their Figure 1 does not provide a basis for comparing welfare costs in second best relative to the first best. This is because the second-best economy, in addition to having welfare costs from pre-existing taxes, also has lower initial emissions.

Our numerical comparisons clarify the combined effects of these two differences. Although the quantitative results of this paper are specific to the particular numerical model, we believe that the qualitative results are more general. The model has thus been used as a vehicle for analysing the economic fundamentals regarding the cost of emission reductions in first- and second-best economies. The insight is that reducing emissions by means of taxes (or auctioned quotas) makes first-best and second-best tax solutions more equal; parts of the tax revenue come from the same source. This has the effect of diminishing the difference in terms of efficiency between first and second-best tax solutions – the excess burden – as the total emission level is reduced and a larger share of total governmental revenue originates with environmental taxes. If the revenue requirement is low and the environmental ambitions high, it is even possible that the first and second-best solutions coincide.[12]

Sandmo (1975) demonstrated what a second-best optimal tax solution looks like in the presence of negative externalities. His results are equally valid in the case of an exogenous emission target, i.e., without having the welfare effects of the negative externality explicitly modelled. The second-best efficient solution *presupposes that the revenue-recycling effect is exploited,* although Sandmo never used this terminology in 1975. Any other way of meeting the combined restrictions on tax revenue and emissions than by way of taxes (or auctioned quotas), is *not second best*. The magnitude of the extra cost when not reducing existing tax rates with the revenue from environmental taxes or auctioned quotas has been demonstrated both in this paper and in e.g. Goulder et al (1997), Håkonsen and Mathiesen (1997), Goulder et al (1999), and Parry et al (1999).

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[11] Actually, it is misleading to speak of gradfathered quotas as a second-best instrument. This intrument is strictly dominated by either a carbon tax or auctioned quotas. A solution obtained by a combination of a labour tax and grandfathered quotas thus belongs to the class of third best or less-than-second-best solutions.

[12] This possibility may be regarded more of theoretical than practical relevance. It fits nicely though into our interpretation of welfare costs of regulation, while it does not square with the interpretaion of Parry et al (1999), as their cost curves diverge.

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Appendix A. The model of Parry et.al. (1999)

There are six intermediate goods; coal (F_C), petroleum (F_P), natural gas (F_N), electricity (E), other energy-intensive intermediate goods (I), and non-energy-intensive intermediate goods (N). Further, there are two final consumption goods: an energy-intensive good (C_I), and a non-energy-intensive good (C_N). Production of intermediate and final goods are described by constant returns nested CES production functions, and each producer takes input and output prices as given. Labour is input to the production of the six intermediate goods, while the two final goods are aggregates of intermediate inputs only.

There is a representative consumer with preferences over leisure (l) and the two final goods, expressed by the utility function

$$U(l, F(C_I, C_N)). \tag{A1}$$

σ^H and σ^F denote the elasticities of substitution between l and $F(\cdot)$, respectively C_I and C_N. The consumer maximises U subject to the budget constraint

$$p_{C_I}C_I + p_{C_N}C_N = p_L L(1-t_L) + \pi(1-t_R) + G - a, \tag{A2}$$

where $L = \overline{L} - l$ is labour supply, t_L and t_R are tax rates on labour and rent income respectively, G is transfer income, which throughout the analyses is kept constant in real terms, and a is a lump sum tax. In the reference equilibrium (without a carbon restrictions), there is no pure profit, $\pi = 0$. When, however, the government uses grandfathered quotas to restrict emissions, π represents the quota rents that accrue to the private sector. It is assumed that $t_R = t_L$.

Carbon emissions stem from the use of coal, natural gas, and petroleum. Each of these has a fixed carbon emission coefficient β_i, $i = F_C, F_N, F_P$, such that total carbon emissions (e) becomes

$$e = \beta_{F_C}F_C + \beta_{F_N}F_N + \beta_{F_P}F_P. \tag{A3}$$

The government's budget constraint equalises total tax revenues (REV) with the lump sum transfer (G),

$$REV = a + t_L L + t_R \pi + t_e e = G. \tag{A4}$$

Under a carbon tax (t_e) , $\pi = 0$, while under a grandfathered quota, $t_e = 0$. In first-best tax solutions, the lump sum tax a is used, while t_L is zero. The opposite is the case in second-best solutions, where we assume that lump sum financing cannot be used, such that the tax revenue requirement must be met by a combination of t_L, t_R, and t_e.

The benchmark data set is collected from Parry et al's Table 1, which represents an approximation to the US economy in 1995. The data and the elasticities of substitution in the various CES aggregates are restated in Appendix B of this paper.

Appendix B. GAMS/MPSGE-code for the Parry model of the US economy

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SETS I     Commodities and sectors
       /FC   Coal
        FP   Petroleum
        FN   Natural gas
        EL   Electricity
        EI   Energy intensive intermediate good
        NI   Non-energy intensive intermediate good
        EC   Energy-intensive consumption good
        NC   Non-energy intensive consumption good /,

       F(I)  Fossile fuel sectors
           / FC, FP, FN /,

       N(I)  Non-fossile fuel sectors
           / EL, EI, NI, EC, NC /

       G(I)  Energy inputs
           / FC, FP, FN, EL /,

       M(I)  Material inputs
           / EI, NI /,

       C(I)  Consumption input
           / EC, NC /;

TABLE AI(*,I) Input to sectors (Mill. of 1995 dollars & Mill. tons carbon)
     FC      FP      FN       EL       EI       NI      EC        NC
FC 2874.4    33.1     0.5   7729.2   3267.6   1453.4    490.8      9.8
FP  414.8 107334.5 22258.5  9823.6  26620.8  26553.9  10092.9   5538.3
FN   10.5  21371.3 36113.9  8987.5  11196.6  12315.4   2761.8    202.8
EL  653.7   3710.2   814.9    48.3  25181.9  41148.8  34003.6     44.5
EI 1569.9  22155.8  1512.5 10879.4  338137.  469948.  116320.   8778.8
NI 4892.5  33651.2 16157.5 38359.5  233261. 3326713.  291455. 2699669.
L  5442.9  20381.1 16102.1 29778.5  331636. 2766027.       0.       0.
E   507.3    598.7   317.6      0.       0.       0.       0.       0.

TABLE ES(*,I) Elasticities of substitution among inputs
        FC     FP     FN     EL     EI     NI     EC      NC
T      0.25   0.19   0.21   0.18   0.17   0.18   0.19   0.22
EN     0.16   0.20   0.89   0.20   0.82   0.53   0.59   0.97
MA     0.53   0.20   0.20   0.95   0.27   1.51   0.26   0.76

PARAMETER
       VH0    Benchmark value of leisure
       TAX0   Benchmark labor tax rate
       PU0    Utility price
       Y0(I)  Benchmark value of inputs
       QUOTA  Total allowed emission
       L0     Benchmark labor supply
       H0     Benchmark volume of leisure
       T0     Benchmark time endowment
       U0     Benchmark utility
       TR0    Benchmark transfer;

* Benchmark parameters

VH0 = 932167.0;
TAX0 = 0.4;
PU0 = 1.0;

* Conversion of observations into parameters

Y0(I) = SUM(G, AI(G,I))+SUM(M, AI(M,I))+AI("L",I);
QUOTA = SUM(I, AI("E",I));
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L0  = SUM(I, AI("L",I));
H0  = VH0/(1-TAX0);
T0  = L0 + H0;
U0  = (Y0("EC")+Y0("NC")+VH0);
TR0 = (TAX0*L0);

$ONTEXT
$MODEL:CO2COST
$PEPS:0.0

$SECTORS:
  AL(I)  ! Activity levels
  WORK   ! Conversion of time to work accounting for tax
  UTIL   ! Utility-index

$COMMODITIES:
  P(I)   ! Produced commodities
  CO2    ! Emission-rights for CO2
  PH     ! Leisure
  PL     ! Labor
  PU     ! Utils
  TRA    ! Transfer

$CONSUMERS:
  CONS
  GOVT

$AUXILIARY:
  TAX

$PROD:AL(F)  s:0.0  a:ES("T",F) b(a):ES("EN",F) c(a):ES("MA",F)
 O:P(F)         Q:Y0(F)
 I:CO2          Q:AI("E",F)  P:0.0
 I:PL           Q:AI("L",F)          a:
 I:P(G)         Q:AI(G,F)            b:
 I:P(M)         Q:AI(M,F)            c:

$PROD:AL(N)  s:ES("T",N)  a:ES("EN",N)  b:ES("MA",N)
 O:P(N)         Q:Y0(N)
 I:PL$AI("L",N) Q:AI("L",N)
 I:P(G)         Q:AI(G,N)            a:
 I:P(M)         Q:AI(M,N)            b:

$PROD:WORK
 O:PL           Q:L0     P:1.0      A:GOVT N:TAX
 I:PH           Q:L0     P:1.0

$PROD:UTIL   s:1.0   a:0.5
 O:PU           Q:U0     P:PU0
 I:PH           Q:H0     P:(1-TAX0)
 I:P(C)         Q:Y0(C)  P:1.0       a:

$DEMAND:CONS
 E:PH           Q:T0
 E:TRA          Q:1
 D:PU

$DEMAND:GOVT
 E:CO2          Q:QUOTA
 D:TRA

$CONSTRAINT:TAX
TRA/PU =E= TR0;

$REPORT:
V:UTILITY O:PU PROD:UTIL
```

```
$OFFTEXT

$SYSINCLUDE MPSGESET CO2COST
OPTION DECIMALS = 8;

PL.FX = 1.0;
PH.L  = 0.6;
CO2.L = 0.0;
TAX.L = 0.4;
TRA.L = TR0;

******* Check the Second Best Calibration

$INCLUDE CO2COST.GEN
SOLVE CO2COST USING MCP;

******* Prepare and solve the First Best  *******
*
* It is advisable to modify model structure, by dropping the AUXILIARY & CONSTRAINT (TAX & TRA)
* rather than modify parameters, i.e., stipulate TR0 = 0.0001
*
******* Recalibrate the model according to First Best solution

PU0 = 0.890389072;
U0  = U0/PU0;
TR0 = TR0/PU0;

******* Regulate the Second Best  *******

SET      Q /1*15/;
PARAMETER REPORT(*,Q);

LOOP (Q,

$INCLUDE CO2COST.GEN
SOLVE CO2COST USING MCP;

REPORT("Emission",Q) = QUOTA;
REPORT("CO2-price",Q)= CO2.L;
REPORT("Utility",Q)  = UTILITY.L/1000;
REPORT("Eq.Var.",Q)  = (UTILITY.L-U0)/1000;

QUOTA = QUOTA - 50;

);

DISPLAY REPORT;
```